Special Events Imager

The Special Events Imager (SEI) is a joint NOAA-NASA mission to be flown as a prototype sensor on the Geostationary Operational Environmental Satellite (GOES) for the purpose of obtaining multispectral visible and near infra-red images of the Earth's surface at a high repeat frequency. These images will be used to monitor and study processes which can vary rapidly in time on land, oceans, and atmospheres (such as floods and fires, river plumes and harmful algal blooms, and storm and cloud development). SEI has a spatial resolution of 300 meters and an image size of 300 x 300 km. It has the capability of providing an image of ten spectral bands every ten minutes, which greatly expands the capability of GOES in spectral coverage, and both spatial and temporal resolution. The images are needed in management of coastal zone resources, and mitigation of natural hazards such as floods, fires, and volcanoes. Data will be processed in near real-time by NOAA and made available for operational users by NOAA. Research data products will be available through NASA.

1.0 SCIENCE

Understanding the effect of short term forcing processes on complex earth systems is essential to the development of predictive models to assess the impacts of long term change. Polar orbiting platforms will carry several visible-near infrared sensors over the next decade, such as the Moderate Resolution Imaging Spectrometer (MODIS) and the Visible/Infrared Imager Radiometer Suite (VIIRS), capable of furnishing highly accurate water-leaving spectral radiance with high spectral and one (1) kilometer resolution at a global revisit period of approximately two days. These rates of coverage, which will be reduced further in the presence of clouds, are sufficient for observing the intrinsic variability of biotic and abiotic phenomena on large spatial (basin-wide) and temporal (annual - decadal) scales. Two day coverage, however, is inadequate to resolve processes operating at shorter time (hours - days) scales. In addition, the current sun-synchronous polar orbiter observations along coasts are aliased with the tidal frequency. High frequency observations are required in order to remove the effects of tidal aliasing and to validate tidal mixing terms in coastal ecosystem models. To study short-term events, data from polar orbiting sensors need to be augmented by comparable data with a higher rate of coverage.

SEI is designed to remedy the coverage contraints imposed by polar orbiting platforms and represents a dual-purpose mission in which applications and science goals complement each other. SEI will acquire high spatial resolution (300 m), multi-spectral, visible-near infrared (380 - 1000 nm) observations on a regional level as frequently as every ten minutes from Geostationary Operational Environmental Satellite (GOES) -N or -O.

The high temporal and spatial resolution data supplied by SEI fills an existing gap in the time-space domain of available visible-near infrared observations obtained from space-borne sensors (Figure 1.0-1), and permit short-term events and processes of the ocean, land, and atmosphere to be detected, monitored, quantified, and predicted. These data will permit the investigation of processes of the dynamic coastal ocean, such as tidal mixing, as well as the study and tracking of ephemeral events in the terrestrial and atmospheric environments, including storm development and volcanic ash plumes.

The high frequency revisit rate can also increase the cloud-free area in a region of broken clouds through cloud filtering and compositing of multiple images. These attributes will strengthen our ability to appraise existing conditions and predict short-term events. Furthermore, augmenting the continuous observations of geostationary platforms with the higher spectral resolution data from polar orbiters will allow the investigation of oceanic processes not possible with either platform separately. Likewise, SEI images can be used to extend the temporal window seen in intermittent observations from very high spatial resolution ocean color sensors like Navy Earth Map Observer (NEMO).

SEI observations will be employed for both scientific (Section 1.1.1) and application (Section 1.1.2) purposes. Scientifically, SEI furnishes data at the rapid time scales required to fully understand and predict the response of marine and terrestrial ecosystem dynamics at longer scales. The data will enable scientists to characterize the interaction between time and space scales in environmental parameters, and

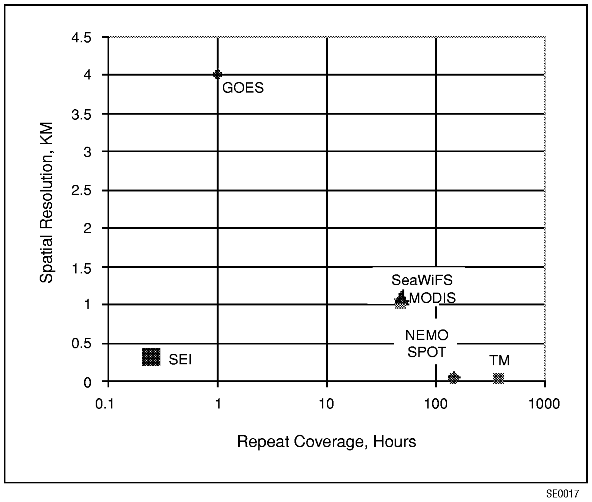

Figure 1.0-1. Space and time domain of observations from existing and planned satellite-borne, visible-near infrared sensors. SEI complements other sensors by supplying high temporal and spatial resolution data with high sensitivities and spectral bands needed for coastal zone research and monitoring.

to quantify (and possibly remove) the effect of tidal and sub-daily frequency events in sun-synchronous polar orbiter observations. From an applications perspective, SEI will assist state and federal agencies in achieving their environmental stewardship and assessment missions and their role in natural hazards detection and monitoring. A partial list of the environment issues that SEI can address include:

- Quantifying the response of marine ecosystems to short-term physical events, such as passage of storms and tidal mixing;
- Monitoring biotic and abiotic material in transient surface features, such as river plumes and tidal fronts;
- Detecting, tracking, and predicting the location of hazardous materials, such as oil spills, ocean waste disposal, and noxious algal blooms;
- Initializing, validating, and running into coupled biological-physical coastal ecosystem models;
- Assessing the effect of tidal aliasing and sub-pixel variability on global estimates from polar orbiting observations;
- Improving the estimates of hurricane intensification and landfall predictions.

1.1 Scientific Goals and Objectives

1.1.1 ESE Research Goals

Can we understand and predict how phytoplankton biomass and productivity are changing in response to climate and environmental change?

Can we understand and predict how the ocean biological "pump" affects the carbon dioxide concentration, and the concentration of other trace gases in the troposphere?

Can we understand and predict how coastal and estuarine ecosystems respond to tidal forcing and natural seasonal-to-interannual variations in river discharge? Can we understand how changes in land cover and land use affect coastal and near shore ecosystems? Can we understand how pollutants or nutrients carried by rivers and by atmospheric circulation affect near shore/coastal ecosystems?

Can we predict changes in sustainable coastal fisheries resources in response to climate and human impact?

The current suite of earth imaging sensors lack the combination of spectral, spatial, and/or temporal capability to address important local scale phenomena of crucial importance to marine and terrestrial accustoms. The missing element is hourly scale imagery with band sensitivities required for ocean color determination. Marine planktonic ecosystems are particular sensitive to this need because they are not fixed in position, and tidal motion and mixing is an important forcing function.

Polar orbiting platforms will carry several ocean color sensors over the next decade, such as the MODIS and the VIIRS, capable of furnishing highly accurate water-leaving spectral radiance with high spectral and 1 kilometer resolution at a global revisit period of approximately two days. The Department of Defense is also preparing a high spatial resolution ocean color mission, the NEMO, which also has a several day revisit rate for coastal zone coverage at mid/low latitudes. These rates of coverage, which would be reduced further in the presence of clouds, are sufficient for observing the intrinsic variability of phytoplankton bloom phenomenon on relevant spatial and seasonal to decadal scales. However, two day coverage is inadequate to address the hourly to daily scales which characterize important coastal and estuarine phenomena such as tidal mixing and fronts, storm surges, as well as diurnal variations in phytoplankton abundance and productivity. While the one kilometer pixels are adequate to resolve tidal excursions, they are less suitable for modeling studies and for investigation of tidal fronts and near-shore processes. In addition, the current sun-synchronous polar orbiter observations along the coasts are aliased with the tidal frequency. High frequency observations are required in order to remove the effects of tidal aliasing and to validate tidal mixing terms in coastal ecosystem models. The present GOES observations are too coarse in spatial, radiometric, and spectral resolution to fully meet these needs. The relation of sampling from the current suite of sensors, to that possible with SEI, is illustrated in Figure 1.0-1.

1.1.1.1 Coastal Marine Ecosystem Variability

There is renewed interest in the complex linkage between productivity and fisheries, and on the impact of human activities on coastal marine ecosystems. The primary production of oceanic biomass is a major factor in the global carbon cycle and a governing factor in the atmospheric CO2 balance. The productivity of the ocean (and especially the coastal zones) sets the fundamental limit on the amount of fish that can be harvested, most of which come from the coastal oceans. These oceanic regions and estuaries are also the most heavily impacted marine environments through land-use change, and other human activities. Large scale ocean color measurements to be provided more or less systematically by a number of satellite missions and operational programs, including ESA/ENVISAT, NASDA/ADEOS-2, NASA/EOS AM-1 and PM-1, and eventually NPOESS (beginning around 2009 form a basis upon which we wish to add a high temporal remote sensing capability.

Optical properties of open ocean waters are dominated by the effects of phytoplankton absorption and scattering, and are termed Case 1 waters. Coastal waters are optically much more complex, and effects of various dissolved materials and suspended sediments must be taken into account both in the atmospheric correction and in-water radiative transfer based algorithms. Algorithms for these Case 2 waters have been developed using in-situ data and are being demonstrated using additional bands in the SeaWiFS and other second generation ocean color sensors, compared to CZCS. Inclusion of these bands on SEI is important for addressing coastal needs. In addition, more recent research stresses the utility of two additional bands (380 nm and 620 nm) for coastal waters. Algorithms using these bands will be evaluated prior to SEI launch, through Japan's GLI and the NEMO program. By including these bands on SEI, the mission will remain current and the data will be applicable to improved coastal Case 2 algorithms.

Tides are a dominant factor affecting coastal marine ecosystems. The dominant scales of physical forcings to coastal marine ecosystems are the tidal mixing scales, daily insolation, storm and wind events, and spring/neap tidal cycles. Spatial variability occurs on all scales, but length scales tend to be shorter near the coasts than in the open ocean. This is primarily due to the constraining influence of the shoreline, the influence of bathymetry on tidal and persistent currents, and nutrient inputs by rivers, and interactions of these terms with biological growth and consumption. Figure 1.1.1-1 shows a myriad of fine structure in ocean color off the coast of Tasmania. These small features tend to have short lifetimes, with a decorrelation time on the order of hours to day. Global imagers such as SeaWiFS and MODIS provide adequate sampling of the open ocean for periods above a day, and provide invaluable data on these scales. However, they are limited in addressing more rapid coastal variations because of the revisit time of two to three days at 1 km resolution. In sampling at the same time period, the effects of tidal forcings are obscured, and aliased into longer term means computed from those data. The next several paragraphs explore the role of tides on coastal planktonic ecosystems, concentrating on effects on phytoplankton.

Figure 1.1.1-2 shows a mixed semi-diurnal tide over a period of 17 days. It happens to be taken along the Oregon Coast. The sampling

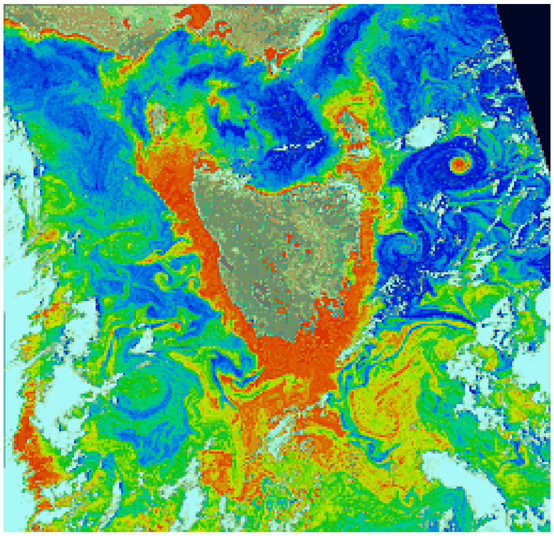

Figure 1.1.1-1. Fine Structure Ocean Color off the Coast of Tasmania SE0012

provided by a polar orbiter, in this case SeaWiFS, is shown at the maximum once per day at noon. Clouds reduce this by at least half to three quarters, and half of the remaining images are on the edges of the image swath. The figure illustrates that it takes two weeks for the polar orbiter to sample the full range from low tide to high tide. During this time, phytoplankton populations have gone through significant changes (10 – 50 generations), and there have been several storm events which have had significant impact on water column mixing and have affected both the biological and inorganic loadings in the water. Potential sampling by a geosynchronous imager is shown as diamonds on October 8, and can capture the full range of tidal stages in a single day. The SEI clearly provides a tremendous improvement in sampling capability.

The tidal data in Figure 1.1.1-3 is strictly for a given point. Tidal stage varies spatially as the wave propagates. The SeaWiFS image of the Chesapeake Bay shows algal blooms and current related features. For any given image, the stage of the tide varies over more than a complete cycle as one progresses from the Bay mouth to the Upper Bay, which is impossible to discern in the SeaWiFS image. Tidal advection in the Bay is such that surface waters move about 8 km up the bay on flooding tides, and about 10 km down the bay on ebbing tides. (In the bottom layers the net movement is toward the upper bay in this classical estuary). This translation of features becomes important for resolution of locations of algal blooms and trajectories of spills and sediments, and in time differences of polar orbiter images. It makes it exceedingly difficult to separate tidal motions of biomass from real temporal changes of growth, consumption, and dilution. Even trying to match features seen in a high resolution TM image (9am) to a coarse resolution but more sensitive SeaWiFS image (noon) is not straight-forward, even on the same day. There may be over a 5 km difference due to tidal motion. With SEI, exact matches to both sets of features could be obtained, plus more throughout the tidal cycle.

Nutrient inputs to the Nantucket Shoals and Georges Bank ecosystems are tidally driven. Strong tidal currents over these shallow regions result in mixing of the entire water column, and distribute nutrients from the bottom regeneration, and from offshore deeper waters, into the upper zone where photosynthesis is maximal. Tidal mixing occurs on both ebb and flood tides, and so has a period of only 6 hours. Tidal motions of patches of phytoplankton which result from these processes

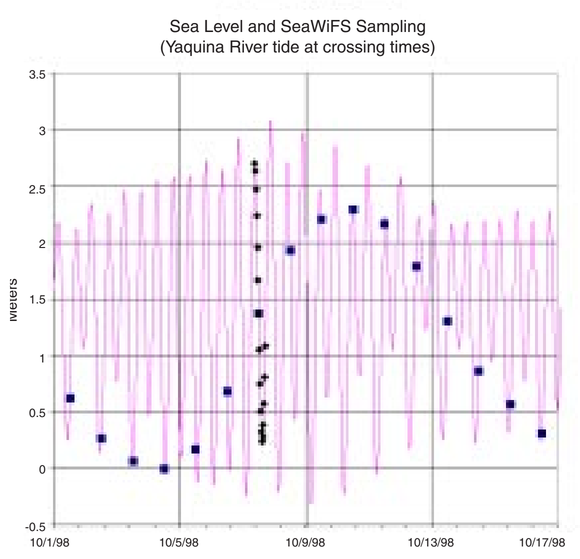

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Figure 1.1.1-2. Sea Level SeaWiFS Sampling (Yaquina River tide at Crossing Times)

Figure 1.1.1-3. SeaWiFS Image of Chesapeake Bay Algal Blooms at 1.13 km resolution

was observed with repeated airborne remote sensing measurements of ocean color studies.

Spring tides and neap tides occur at full moon and new moon, respectively, and tend to be higher than when the moon is perpendicular to the earth-sun axis. Therefore tidal currents are stronger during spring and neap tides, which results in greater mixing of the water column (mixing is proportional to the cube of the current speed). This results in fortnightly tidal mixing maxima (near Oct., which has been documented as a significant estuarine forcing mechanism. Again, documenting tidal effects using only polar obiter observations is difficult to impossible, since the Nyquist sampling criterion is not met.

Tidally driven mixing is an important physical forcing to regional ecosystems wherever rates of tidal energy dissipation are high. Because of the resulting high biological production, these are important fishing areas, and include the various Banks off NE North America, the Argentine shelf off South America, the Indonesian Archipelago, Bering Sea, and the North Sea and English Channel.

Understanding the coupling of these strong physical forcings and motions with estuarine and marine ecosystems will require good observational capability and the development of robust, coupled physical/biological models. Such models are in varying stages of development by several research groups. These models would form a good basis for scientific data assimilation of SEI observations. The success of such data assimilation models is prerequisite to developing a good predictive capability for the coastal zone, and synoptic observations at appropriate time intervals is necessary for this work to progress efficiently.

Like most plants, phytoplankton exhibit strong diurnal periodicities in photosynthetic capacity, but these are rarely symmetrical about noon. Chlorophyll biomass also changes throughout the day. These diel differences must be accounted for in models of phytoplankton photosynthesis or primary productivity which are applied to global data sets from polar orbiters, all taken at identical times in the photoperiod. SEI will provide a means to evaluate and broaden the assessment of such effects, on a regional stratified sampling basis.

1.1.1.2 Terrestrial Ecosystem Research

The major benefits to Terrestrial Ecosystem research involve the ability to assess short term variability in vegetation and land cover properties. Visible remote sensing, and light harvesting, are functions of the bidirectional reflectance distribution function (BRDF). SEI will provide the capability to assess spatial variation in BRDF by observing the same region throughout the day. Additionally, the sensitivity of BRDF to wind effects, and moisture stress can be quantified with SEI observations.

An additional benefit of SEI will be to increase the probability that key test sites can be imaged during critical field studies. Multiple images can be obtained which will reduce the chances of cloud obscuration. This is especially important for areas with strong daily variations in cloud cover, or areas which are prone to broken and partial cloudiness from cumulus clouds.

MIT’s Lincoln Lab (LL) studies of the high sensitivity of SEI indicate that bright fires will also be visible at night, in addition to the visibility of smoke plumes during the day. This will aid in the investigations of the impact of fires on ecosystems and land cover change.

As in marine ecosystems, plants show pronounced variation in photosynthetic capacity during the daylight period. SEI will be useful in studying such diurnal variability in remotely sensed reflectance and vegetation canopies, and will be a significant adjunct to the VCL mission.

1.1.2 Applications

The high temporal and spatial resolution of SEI data, which permits the scientific investigation of ephemeral events, will also prove useful in application-oriented activities. SEI imagery will assist state and federal agencies in achieving their environmental stewardship and assessment missions and their role in natural hazards detection and monitoring. Furthermore, the near-real time access of these multispectral images will be useful in the monitoring and mitigation of a variety of natural hazards including oil spills, toxic algal blooms, floods, fires, and volcanoes.

In general, SEI imagery, separately and in combination with data from polar orbiting sensors, may be employed to:

- Assess the geological and biological response to storm and other short-term events;
- Initialize and validate operational, coastal circulation models;
- Observe biotic and abiotic material in transient features;
- Detect, monitor, and track natural hazards, such as fires, volcanic ash clouds, and toxic algal blooms; and
- Improve estimates of hurricanes intensification and landfall predictions.

Several applications are described briefly below:

Toxic Algal Blooms. SEI will offer a valuable tool in detecting, monitoring, and tracking toxic algal blooms. These biological events, often referred to as "red tides" because their presence may discolor the water a reddish hue, often pose a significant risk to human health and detrimentally affect regional economies and marine resources. (See Figure 1.1.1-4.) The ocean color bands of SEI permit the detection of algal blooms in general, and potentially the identification of those blooms composed of toxic species, such as those illustrated in Figure 1.1.1-5. The band at 380 nm is especially useful, according to recent research.

Some toxic algal species, the dinoflagellates, undergo diurnal migration, swimming to depth at night and rising to the surface only around midday. Ocean color sensors on polar orbiting platforms, which generally possess equatorial crossing times + 2 hours centered on noon, could conceivably fly over the area while the blooms were at depth and not detect them. This is unlikely with the numerous daily observations afforded by SEI. Furthermore, the high frequency of SEI observations improves our ability to locate and track these blooms by increasing the cloud-free area in a region through cloud filtering and compositing of multiple images. Detecting the presence of toxic algal blooms provides valuable information that may be used to mitigate their effects, both medical and financial.

Information on the large (100 m) scale distribution of toxic algal blooms could be employed, for example, in selecting which specific regions should be closed to harvesting because of exposure to toxins, while leaving those untainted regions open. Currently in California, entire coastal areas are closed when toxic blooms are reported without regard to distribution of the bloom and result in a reduced catch of edible shellfish.

Coastal Circulation. The Advance Short-Term Warning and Forecast Service component of NOAA’s environmental assessment mission will benefit greatly from the subtidal frequency afforded by SEI data. These data can be used to initialize and validate regional, coastal circulation models. SEI data would provide surface flow field vectors, as calculated by tracking features using wavelet analysis in sequential imagery. The flow vectors can be assimilated into nowcast and forecast models. These resulting flow fields can be applied to address several items, such as predicting the timing and landfall of hazardous materials in coastal waters.

In a similar manner, SEI data can be used to monitor and track biotic and abiotic material in transient surface features, such as river plumes and tidal fronts. Data from polar orbiting sensors are likely not capable of resolving the daily spatial changes in these materials. Feature tracking using SAR is being developed by NOAA’s CoastWatch program and could be readily adapted to SEI imagery.

Sea Ice. Sea ice represents a potentially lethal obstacle to commerce and transportation in certain regions of the United States. The

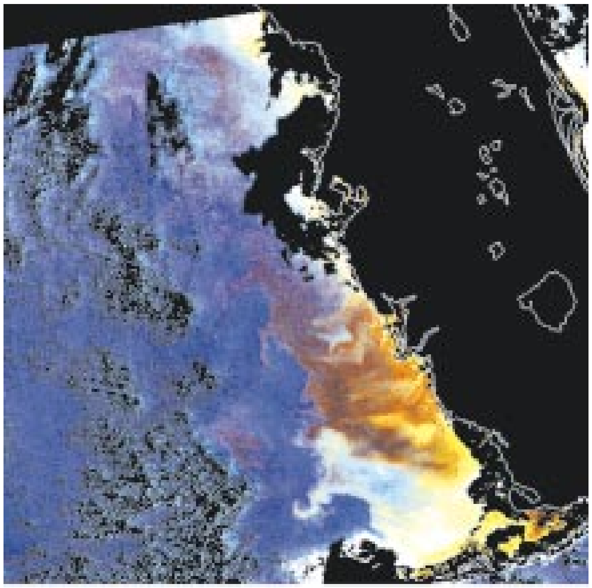

Figure 1.1.1-4. True-color composite of CZCS image from November 14, 1978. Contemporaneous in-situ sampling sites are indicated by yellow crosses.

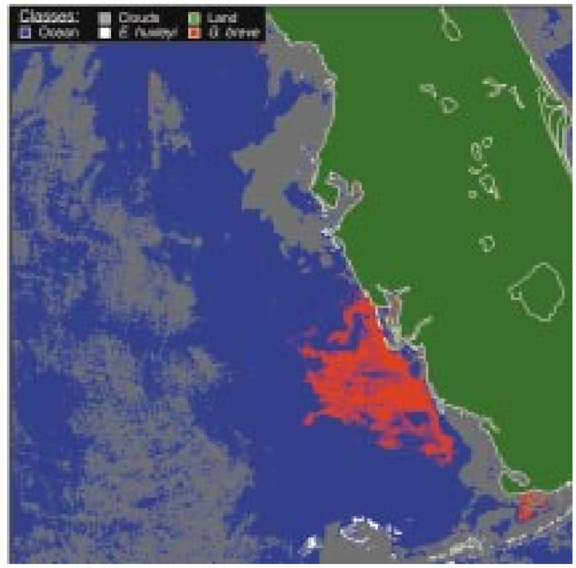

Figure 1.1.1-5. Classified counterpart of CZCS image presented in Figure 1.1.1-4. This algorithm was designed for use with CZCS imagery in waters off the western coast of Florida. The algorithm has been implemented to use SeaWiFS data from the Gulf of Mexico.

ability to estimate the size and concentration of sea ice, particularly at the high spatial resolution provided by SEI, could be used to assess risks to vessel passage through in shipping lane and to chart the most efficient, ice-free path through an area. Feature tracking developed by CoastWatch can be applied to the ice edge and coastal leads and polynyas using simalar techniques.

Bathymetric Changes. The resuspension and subsequent settlement of sediments after the passage of storm fronts often result in a re-distribution of sediments. This change in regional bathymetry, typically of no consequence, can deleteriously affect shipping in certain coastal areas, such as channels and ports. A ferry, for example, was grounded for several days off Block Island, Rhode Island while attempting to dock after heavy weather had re-distributed sand to form shoals where none had been present before. Data from the ocean color bands of SEI will permit the estimation of bathymetry, ranging from one to several meters in depth depending upon attenuation of the water.

Water Clarity. Estimating the clarity of water has both civilian and military applications. From a military perspective, knowing and predicting the visibility of waters off a region of conflict would prove valuable in planning and conducting underwater activities. For civilian purposes, remotely estimating water clarity is helpful in monitoring aspects of water quality and surveillance of single-point sources of pollution. The envisioned complement of ocean color bands on SEI should provide an adequate estimation of visibility, and its capability to observe the site frequently increases the probability of obtaining cloud-free imagery and monitoring any changes.

Fires. Fires, specifically those resulting from the uncontrolled burning of trees, brush, and grass, are capable of inflicting a loss of limb, life, and property. SEI, with its high temporal and spatial resolution, offers a method to locate and track fires at finer scales than obtainable from AVHRR and GOES imagery. SEI will complement the relatively coarse imagery of these sensors by detecting and pin-pointing the location of small scale (< 1 km) fires. This fine-scale information may be employed to evaluate the number and location of existing fires, deploy fire control and prevention units, and select evacuation routes.

Volcanic Ash Clouds. Plumes comprised of volcanic ash injected into the atmosphere pose serious dangers to flying aircraft. After a plume is detected in imagery from polar or geostationary satellites, SEI could aid in mapping the small scale distribution of these plumes and its change over time.

Floods. As with fires, floods claim both life and property. The 300 meter resolution of SEI and its ability to distinguish water from land with its near-infrared bands permit the location of flood waters to be mapped more frequently and in greater detail than the current polar and geostationary sensors. These finer resolution measurements can assist in assessing and predicting flood stage, choosing appropriate evacuation routes, and improving estimates of damage incurred by flood waters.

Storm Development. A significant amount of effort is spent in predicting the timing and location of severe storms and alerting the public of their occurrence. SEI will aid in the detection and monitoring of these atmospheric disturbances on regional scale.

In addition, the Tropical Prediction Center of the National Hurricane Center has also suggested that ocean color data, acting as a proxy for ocean mixing, may improve estimates of hurricane intensification and predicted landfall.